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Regional Cost Estimates for Rehabilitation and Maintenance Practices on Army Training Lands

by
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The U.S. Army is responsible for managing millions of acres of land used to support a variety of training and testing activities. Increased use of this land results in deterioration that can adversely affect mission requirements and safety. Various land rehabilitation and maintenance (LRAM) practices can offset this deterioration by physically or biologically controlling erosion and stabilizing land surfaces with vegetation. These practices frequently include the use of heavy equipment and farming implements to manipulate site characteristics, install erosion control materials and structures, prepare seedbeds, apply soil amendments, and seed or transplant vegetation. Planning, designing, budgeting, and implementing comprehensive LRAM projects requires information concerning component costs associated with erosion control and revegetation. Differences in climate, geology, soils, and vegetation types between Army installations, however, results in significant cost variability.

This report summarizes current, regional cost data obtained from various Federal, State, and private agencies concerning LRAM practices. In general, LRAM costs were highest in the Pacific Coast, Intermountain, and Northeast regions of the United States and lowest in the Great Plains and Cornbelt regions. This reflects regional differences in costs of goods and services, proximity to larger cities capable of providing necessary LRAM equipment and services, and proximity to production agriculture enterprises.

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Foreword

This study was conducted for the Conservation Division, Directorate of Environmental Programs, Office of the Assistant Chief of Staff for Installation Management under Reimbursable Order No. E8793042, "Cost Estimates for Maintenance of Army Training Lands." The technical monitor was Vic Diersing, DAIM-ED-N.

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COL James T. Scott is Commander and Acting Director of USACERL, and Dr. Michael J. O'Connor is Technical Director of USACERL.

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1 Introduction

Background

The U.S. Army is responsible for managing about 12.4 million acres of land used to support a variety of military training and testing activities (U.S. Department of the Army 1989). This land base, however, is considered inadequate for meeting existing training mission requirements (U.S. Department of the Army 1978). Increased use of this limited land resource in recent years has resulted in a gradual deterioration in the condition of natural resources assets at Army training facilities within the United States (Diersing and Severinghaus 1984; Goran, Radke, and Severinghaus 1983; Johnson 1982). To offset the deterioration caused by military training and testing activities, installation land managers rely on various rehabilitation and maintenance practices to maintain or reestablish the ecological integrity and stability of training lands. These practices frequently include the use of heavy equipment and farming implements to manipulate site characteristics, install erosion control materials and structures, prepare seedbeds, apply soil amendments, and seed or transplant vegetation. Planning, designing, and implementing comprehensive land rehabilitation and maintenance projects requires information concerning associated component costs (e.g., earthwork, sediment fence, tillage, fertilizer application, seeding, etc.). However, due to significant differences in climate, geology, soils, vegetation types, mission requirements, and proximity to large population centers between Army installations, the cost of seedbed preparation, fertilizing, and revegetating damaged training areas, for example, will vary widely.

Because of the variability in land rehabilitation and maintenance (LRAM) costs between installations located in the United States, the Directorate of Environmental Programs asked the U.S. Army Construction Engineering Research Laboratories (USACERL) to coordinate the assembly of regional cost data for use by installation land managers. In addition to providing regionally specific cost data essential for budgeting, planning, and designing LRAM projects, these data are also useful for selecting the most appropriate practice based on relative costs and desired results. For example, the cost of drilling grass seed might be 1.5 times greater than the cost of broadcasting seed, but improved germination and establishment of drilled seed compared to broadcasted seed compensates for the difference in cost, especially on highly erosive sites requiring immediate vegetative stabilization. Although actual

costs for rehabilitation and maintenance practices will undoubtedly change and require update over time, relative costs between practices should remain somewhat constant, ensuring their applicability well into the future. In response to the request by the Directorate of Environmental Programs, USACERL began an effort to assemble regional cost estimates pertaining to the component activities associated with LRAM practices.

Objectives

The objective of this report is to provide current, regionally based cost estimates for the component activities associated with land rehabilitation and maintenance.

Approach

The first task in this research project was to divide the United States into regions with grossly similar climates, geology, soils, and vegetation types. This division into regions is presented in Chapter 2.

The next task involved identifying and contacting various Federal, State, and private agencies within each defined region concerning availability and access to current LRAM cost data. Appendix A references these data sources.

Assembling and compiling cost data obtained from respondents represented the final task of this research project. Chapter 3 summarizes the results by region and LRAM practice.

Scope

The results of this project have applicability to all U.S. Army installations within the United States, except for Hawaii. The data presented in this report should be used with caution and only as a general reference for decisionmaking. It should be noted that without periodic update, the actual cost estimates presented in this report may not be representative for more than a few years. Relative costs between different LRAM practices should, however, remain reasonably constant.

Mode of Technology Transfer

The information in this report will be used by installation land managers and natural resources personnel for planning, budgeting, designing, and implementing land maintenance and rehabilitation projects.

Metric Conversion Factors

U.S. standard units of measure are used in this report. Metric conversion factors are listed below.

1 ft	=	0.304 m
1 acre	=	0.407 hectare
1 ton	=	907 kg
1 sq yd	=	0.836 m ²
1 cu yd	=	0.764 m ³
1 gal	=	3.78 L
1 lb	=	454 g

2 Project Details and Data Collection

For the purpose of obtaining regional cost estimates associated with LRAM practices, the United States was divided into seven regions based on gross similarities in climate, geology, soils, and vegetation types (U.S. Department of Agriculture, Natural Resources Conservation Service 1981). These seven regions and the states included in them are listed below.

1. Pacific Coast: California, Oregon, and Washington;
2. Intermountain: Arizona, Idaho, Nevada, and Utah;
3. Northern Great Plains: Montana, Nebraska, North Dakota, South Dakota, and Wyoming;
4. Southern Great Plains: Colorado, Kansas, New Mexico, Oklahoma, and Texas;
5. Central Lake: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, and Wisconsin;
6. Northeast: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and West Virginia; and
7. Humid South: Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, and Virginia.

Data for Alaska was very difficult to obtain because of the state's remoteness and diversity in climate, geology, soils, and vegetation types. Most agencies contacted indicated that adding an additional 30 to 50 percent to cost estimates for the Pacific Coast region would provide reasonable estimates for costs associated with LRAM practices in Alaska. The limited data collected from Alaskan agencies supports this generalization.

Within each region, various Federal, State, and private agencies were contacted concerning their ability to provide current component cost data regarding LRAM practices. Appendix A references these data sources. Component costs refer to those associated with a specific kind of activity or task. For example, a rehabilitation and maintenance project designed to control erosion through the reestablishment of vegetation might include the following component activities: (1) earthwork to fill gullies or reduce slope length and gradient, (2) plowing or disking to prepared a seedbed for planting, (3) application of soil amendments to enhance soil fertility and

subsequent plant growth, (4) drilling or broadcasting seeds on the prepared site, and (5) mulching the seeded site to protect it from further erosion while the newly seeded vegetation becomes established. Each of these five component activities has a cost associated with it; these are the types of costs presented in this report.

Unless otherwise noted, all costs in this report represent installed costs that include materials, labor, and equipment needed to satisfactorily perform the work. These costs are based on average-sized jobs done by experienced contractors, operators, and vendors. Materials costs can be reduced if local or installation resources such as riprap, gravel, straw, or plant materials are available for use. Labor and equipment costs can be reduced by using engineer troop personnel and machinery for LRAM projects whenever circumstances present this opportunity. Certain component activities, such as disking and broadcasting seed, or disking and applying fertilizer, for example, can also be combined to reduce costs if conditions and project objectives permit.

Only cost data from LRAM practices applied after 1 September 1991 were considered current and used in this report. It is important to note that much of the data used to compile cost estimates were derived from agricultural surveys and research that may not be entirely representative of conditions encountered on Army training lands. Significant differences between these costs, which are based on large scale, extensively managed agricultural land areas, and costs presented in publications such as Means (1994) and A.C.E. (1994), which are based on smaller scale, intensively managed urban landscape and construction areas, should be expected. For smaller LRAM projects with limited scope, Means (1994) and A.C.E. (1994) are excellent cost estimating resources.

Although the cost data published in this report include averages, the price ranges presented are probably more useful for several reasons. Site conditions can vary greatly. In some instances, difficult site conditions can increase costs whereas ideal conditions often decrease costs. Types of equipment capable of accomplishing similar tasks also vary considerably in availability and cost of operation. Unusual circumstances affecting the amount of time required for task completion, such as extremely wet, frozen, rocky, or clayey soils, may also result in significant cost variability. Distance to job site and overall job size have dramatic effects on cost. Smaller jobs will generally have higher per unit costs than large jobs. Unionized versus nonunionized labor sources and government versus nongovernment contracts also have major impacts on cost. The cost data presented here are not meant to be all inclusive, but rather should be used with caution and only as a guide upon which to base solid decisions.

3 Types of Maintenance and Rehabilitation Activities

Commonly used land rehabilitation and maintenance practices can be divided into several categories depending on project objectives or the extent and severity of site degradation. These categories involve manipulating undesirable vegetation occurring on the site; manipulating physical site characteristics; installing physical or biological erosion control measures; preparing seedbeds for planting; applying soil amendments to enhance soil water retention, nutrient supplying capacity, and overall plant growth and development; establishing vegetation through direct seeding or transplanting; and safeguarding revegetation efforts, through the use of mulch, for instance, to ensure the greatest probability of successful revegetation.

Manipulating Existing Vegetation

Manipulating unwanted or undesirable vegetation is usually accomplished by applying selective or nonselective herbicides. Selective herbicides kill or damage individual species or groups of species with little or no injury to other plant species, whereas nonselective herbicides kill or damage all plant species. Both general types of herbicides are manufactured in formulations (liquids, granules, pellets) that can be sprayed directly on foliage or broadcast on the soil surface using ground rigs, aircraft, or individual plant application techniques (Bovey 1977; Vallentine 1989).

Table 1 provides regional cost estimates for the different types of herbicide application techniques. Due to differences in herbicide selectivity, mode of action, application rates, manufacturing costs, and intended use at individual sites, the price of herbicides is not included in these estimates. Appendix B, however, provides a list of the most commonly used herbicides and purchase prices associated with them. For all regions, the low end of the cost estimate range represents ideal conditions (i.e., large acreages; dry, loamy, level soil surfaces; small stature, undesirable herbaceous plant species with modest plant densities; reduced application rates; owner-operated equipment), whereas the high end represents difficult conditions (i.e., small acreages; wet, clayey, sloping soil surfaces; large stature, undesirable woody species with high plant densities; increased application rates; contractor owned and operated equipment).

Table 1. Regional average costs and ranges for ground and aerial application of foliar and soil active herbicides.

Region	Estimate type	Herbicide Type and Application Method			
		Ground Applied Foliar Herbicide	Aerially Applied Foliar Herbicide	Ground Applied Soil Active Herbicide	Aerially Applied Soil Active Herbicide
Pacific Coast	Average	13.82/acre	11.50/acre	*	*
	Range	7.25-22.00/acre	10.75-12.75/acre	*	*
Intermountain	Average	15.05/acre	11.96/acre	8.36/acre	*
	Range	2.25-25.00/acre	4.12-15.00/acre	4.31-18.00/acre	*
Northern Great Plains	Average	5.27/acre	5.38/acre	5.11/acre	*
	Range	2.00-12.00/acre	2.00-12.39/acre	2.00-8.63/acre	*
Southern Great Plains	Average	7.54/acre	7.31/acre	15.68/acre	34.25/acre
	Range	2.60-16.00/acre	2.00-21.00/acre	2.00-45.00/acre	32.00-45.00/acre
Central Lake	Average	5.84/acre	5.58/acre	4.66/acre	*
	Range	1.75-12.00/acre	3.00-8.30/acre	2.00-12.50/acre	*
Northeast	Average	7.26/acre	7.83/acre	5.83/acre	*
	Range	3.41-12.00/acre	5.00-10.00/acre	5.00-7.00/acre	*
Humid South	Average	5.86/acre	4.25/acre	6.84/acre	*
	Range	3.00-14.00/acre	3.00-8.15/acre	3.00-15.00/acre	*
* Indicates data not available					

The Intermountain and Pacific Coast regions tended to have average foliar herbicide application costs (ground rig and aircraft) that were much higher when compared to other regions (Table 1). This is a reflection of the long distances separating LRAM sites and reasonably-sized population centers offering custom herbicide application in the Intermountain region, and generally higher costs of goods and services within the Pacific Coast region. Although aerial herbicide application costs in most regions were generally lower than ground rig application costs, aerial applicators will not usually spray small, disjointed acreages that may characterize some LRAM sites.

The average cost of broadcasting herbicide granules on soil surfaces was nearly twice as high in the Southern Great Plains region as in other regions (Table 1). Certain areas within this region have significant problems with brush encroachment (Hennessy et al.1983; Johnson and Mayeux 1990) and much of the broadcasted granular herbicide used is applied to individual shrubs and trees. Individual plant application techniques are labor intensive (Bovey 1977) and this is reflected in both the average cost and cost ranges pertaining to this region. The encroachment problem

Chaining, shredding/chopping, and controlled burning are also useful for manipulating unwanted or undesirable vegetation (Scifres 1980). Chaining consists of dragging heavy anchor chain behind two tractors traveling in a parallel direction and is effective for removing even-aged, mature, non-sprouting, single stemmed tree species. Its use is confined primarily to Pacific Coast, Intermountain, and Southern Great Plains regions where costs range from \$15 to \$41 per acre (Table 2), depending on site characteristics and tree density.

Shredding/chopping methods are usually less effective than other mechanical treatments for controlling vegetation. Repeated treatments are often necessary for reasonable control, especially on sites dominated by herbaceous perennial, sprouting, or low growing vegetation (Vallentine 1989). Increased costs can be expected on sites with steep slopes, wet soils, and vegetation types dominated by small trees or shrubs, such as those characteristic of Pacific Coast, Intermountain, and Southern Great Plains regions (Table 2).

Most of the costs associated with controlled burning are related to fire control (Bidwell and Masters 1993). High fuel loads, woody vegetation types, rough or dissected topography, close proximity to adjacent landowners, and strong regulatory requirements all increase controlled burning costs. In light of these considerations, it is not surprising that the Northeast, Humid South, and Central Lake regions have controlled burning costs well above those for other regions (Table 2).

Manipulating Site Characteristics

Many disturbed sites require techniques that are specifically designed to repair gully erosion, modify slope lengths and gradients, control the direction and velocity of runoff, and trap and retain water in terraces, trenches, and furrows. Most of these techniques require some form of earthwork involving excavation, fill material, topsoil, and/or grading and shaping.

Table 3 provides regional cost estimates for these types of activities. Contractor-owned equipment, remoteness of the job site, steep slopes, and wet, rocky soils contribute to increased earthwork costs. Long haul distances (greater than 300 ft) over unimproved roads with steep grades can significantly increase earthwork costs (U.S. Department of Agriculture, Forest Service 1994) beyond those indicated in Table 3 and must be estimated for each project. Compared to other regions, excavation, fill material, and grading and shaping costs are highest for the Northeast and Pacific Coast. Altered excavation, storage (if required), and spreading will increase the costs associated with topsoil for all regions. This is especially pronounced in the Inter-

Table 3. Regional average costs and ranges for earthwork associated with manipulating site characteristics.

Region	Estimate Type	Type of Earthwork					
		Excavation or Fill Material *	Topsoiling *	Grading and Shaping *	Terracing *	Furrowing	Trenching *
Pacific Coast	Average	1.97/cy	2.47/cy	1.97/cy	1.30/lf	25.00/acre	1.13/ lf
	Range	0.80-3.20/cy	1.50-3.20/cy	0.80-3.20/cy	1.00-1.65/lf	15-30/acre	0.70-1.37/lf
Intermountain	Average	1.33/cy	2.45/cy	1.33/cy	0.96/lf	15.00/acre	0.88/lf
	Range	0.72-2.08/cy	0.72-8.05/cy	0.72-2.08/cy	0.75-1.20/lf	12-25/acre	0.52-1.16/lf
Northern Great Plains	Average	1.08/cy	1.19/cy	1.21/cy	1.14/lf	14.87/acre	0.63/lf
	Range	0.72-2.08/cy	0.72-2.58/cy	0.80-1.85/cy	0.70-2.00/lf	12-20/acre	0.20-1.00/lf
Southern Great Plains	Average	0.96/cy	1.04/cy	1.02/cy	0.94/lf	6.43/acre	0.41/lf
	Range	0.60-2.25/cy	0.60-2.75/cy	0.60-2.25/cy	0.48-1.40/lf	5-8/acre	0.29-0.88/lf
Central Lake	Average	1.62/cy	1.72/cy	1.73/cy	1.47/lf	**	0.76/lf
	Range	0.60-3.00/cy	0.60-3.35/cy	1.00-3.00/cy	0.60-2.75/lf	**	0.60-1.50/lf
Northeast	Average	2.63/cy	2.82/cy	3.43/cy	2.58/lf	**	0.95/lf
	Range	1.25-6.23/cy	1.25-6.23/cy	2.00-5.00/cy	1.27-5.00/lf	**	0.90-1.37/lf
Humid South	Average	1.56/cy	1.78/cy	1.46/cy	0.69/lf	**	**
	Range	0.63-2.83/cy	0.85-3.15/cy	0.63-2.00/cy	0.18-1.44/lf	**	**
* cy = cubic yard; lf = linear foot ** Indicates data not available or not applicable							

mountain region, where specialized retrieval and storage practices are necessary to salvage the limited topsoil some relatively young, arid soils have managed to develop (Buol, Hole, and McCracken 1980) (Table 3). Means (1994) presents more detailed information concerning estimating costs associated with different earthwork equipment and practices.

Contour terracing, trenching, and furrowing are used to intercept and control moderate amounts of runoff, thereby conserving rainfall and reducing the potential for accelerated erosion and sedimentation (Laflen et al. 1985). Terraces and trenches can be classified by alignment, cross section, grade, and outlet. They may or may not be parallel, may or may not be vegetated, may be level or on a grade, and may have surface or underground outlets, both, or neither (Laflen et al. 1985). Cost data indicate

that terracing and trenching are generally more expensive in the Northeast and Pacific Coast regions (Table 3) when compared to other regions.*

Contour furrowing, on the other hand, is a shallower and less disruptive soil surface manipulation than terracing and trenching. Furrows have been successfully used to control moderate amounts of runoff, improve infiltration, and increase the amount of water available for plant growth in the western United States (Vallentine 1989). It should be noted that seeding can often be combined with a shallow furrowing operation on many areas if site conditions and seasonal climatic constraints permit. Contour furrowing practices are substantially higher in cost for Pacific Coast, Intermountain, and Northern Great Plains regions when compared to the Southern Great Plains (Table 3). Increased soil water contents, soil water depth, biomass production, rooting depth, and resultant prolonged green growth periods following rangeland furrowing are responsible for the widespread use and resultant lower costs seen in the Southern Great Plains.

Biological and Physical Erosion Control Practices

Following manipulation of existing vegetation and site characteristics, it is often desirable to install biological and physical erosion control practices that maintain site integrity prior to or concurrent with revegetation efforts. Two of the more common biological erosion control practices are grassed waterways and vegetative filter strips. Grassed waterways provide an energy dissipating vegetative mat over which deliberately concentrated runoff can flow without causing excessive erosion (Laflen et al. 1985). Grassed waterway costs include associated earthwork (grading/shaping), seedbed preparation, soil amendments, and seed from species adapted for this purpose. Regions with higher average annual precipitation and greater probability for high intensity precipitation events, such as the Northeast and Humid South, generally have increased grassed waterway costs (Table 4). Higher costs can be expected on remote sites with steep slopes and unfavorable soil conditions (e.g., wet, clayey, or rocky). Cost ranges shown in Table 4 illustrate this variability due to adverse site characteristics and remoteness.

Vegetative filter stripping with annual or perennial species that have the ability to quickly germinate and subsequently develop extensive root systems offers a means to slow runoff velocity and trap suspended sediment behind the upslope side of vegetation strips. Filter stripping costs include seedbed preparation and seed. Increased costs

* Although the average cost was used for most comparisons, the range of costs was broad enough in many cases to warrant additional consideration that changed the regional rankings.

Table 4. Regional average costs and ranges for biological erosion control practices.

Region	Estimate Type	Type of Practice	
		Grassed Waterways	Filter Stripping
Pacific Coast	Average	575.00/acre	21.66/acre
	Range	200-1000/acre	10-30/acre
Intermountain	Average	556.66/acre	11.95/acre
	Range	385-785/acre	9-16/acre
Northern Great Plains	Average	834.00/acre	11.23/acre
	Range	650-1000/acre	4-20/acre
Southern Great Plains	Average	796.00/acre	12.00/acre
	Range	450-1307/acre	6-16/acre
Central Lake	Average	1783.00/acre	12.73/acre
	Range	750-3700/acre	10-15/acre
Northeast	Average	1881.00/acre	19.27/acre
	Range	790-3500/acre	8-35/acre
Humid South	Average	1157.00/acre	16.38/acre
	Range	510-2265/acre	7-25/acre

can be expected on longer, steeper, or more unstable slopes that require strips to be planted closer together for effectiveness. This is especially true for regions prone to high intensity rainfall such as the Pacific Coast, Northeast, and Humid South (Table 4).

Physical erosion control practices include diversion ditches, sediment retention ponds, gabions, riprap, and sediment fencing. All of these practices are directed towards diverting runoff to or concentrating flow on areas less prone to erosion, reducing runoff volumes and velocities, or trapping suspended sediments before they move off-site (Laflen et al. 1985). Similar to site manipulation practices involving earthwork (Table 3), installation costs for diversions and sediment retention ponds were much higher in the Northeast than in other regions (Table 5). Costs for installing gabions, riprap, and sediment fence, however, were greatest for the Humid South region (Table 5) where frequent, high intensity precipitation events mandate material types capable of withstanding the additional stresses imposed by these events. Data concerning physical erosion control materials and structures such as cabled and tri-lock blocks, flumes, chutes, and culverts were extremely limited, displayed uncommon variability, and, consequently, are not presented here. The costs associated with these

Table 5. Regional average costs and ranges for physical erosion control practices.

Region	Estimate Type	Type of Practice				
		Diversion Ditches	Sediment Retention Ponds	Gabions	Riprap	Sediment Fence
Pacific Coast	Average	1.23/lf	2.19/cy	85.14/cy	38.72/cy	2.46/lf
	Range	0.80-1.47/lf	1.17-3.20/cy	77-100/cy	25-71/cy	2.00-3.00/lf
Intermountain	Average	1.38/lf	1.66/cy	81.42/cy	39.34/cy	2.20/lf
	Range	0.72-2.08/lf	1.00-2.08/cy	50-110/cy	31-55/cy	1.80-3.00/lf
Northern Great Plains	Average	1.17/lf	1.26/cy	90.66/cy	28.58/cy	1.59/lf
	Range	0.72-2.13/lf	0.80-2.06/cy	40-135/cy	14-40/cy	0.45-3.25/lf
Southern Great Plains	Average	0.83/lf	1.00/cy	107.20/cy	29.90/cy	2.49/lf
	Range	0.60-1.10/lf	0.65-1.75/cy	70-185/cy	17-49/cy	0.90-3.00/lf
Central Lake	Average	1.67/lf	1.84/cy	69.64/cy	32.42/cy	2.32/lf
	Range	0.75-2.65/lf	1.24-3.00/cy	50-100/cy	20-47/cy	1.80-3.00/lf
Northeast	Average	3.44/lf	2.92/cy	122.00/cy	37.20/cy	3.31/lf
	Range	0.90-10.00/lf	1.75-5.00/cy	90-160/cy	26-56/cy	2.20-4.00/lf
Humid South	Average	1.04/lf	1.52/cy	129.10/cy	40.01/cy	3.75/lf
	Range	0.31-2.00/lf	0.63-2.00/cy	70-275/cy	22-60/cy	2.00-7.50/lf
* cy = cubic yard; lf = linear foot						

materials and structures are probably best approached on a project-specific basis using vendor, contractor, or engineering specifications.

Seedbed Preparation

Choosing a seedbed preparation method depends on several site-specific criteria including slope, kinds and amounts of existing vegetation, and soil type, depth, texture, chemistry, and stoniness (Vallentine 1989). More common methods involve using fire, herbicides, and mechanical farming implements. Fire and herbicidal methods use direct seeding into vegetation that has been recently burned or sprayed. These methods are often lower in cost than mechanical seedbed preparation. However, there are distinct disadvantages that preclude their widespread use. Heterogeneous burns due to insufficient fuel loads, presence of competitive vegetation that sprouts in response to fire, and potential soil crusting problems limit the applicability and success of fire as a seedbed preparation tool (Vallentine 1989). Lack of complete kill, residue

toxicity, or excessive dead mulch and litter from sprayed vegetation may subject newly planted seedlings to herbicide stress and undue competition for light, nutrients, and water that can result in seeding failure. If the above disadvantages can be overcome, fire and herbicides are effective seedbed preparation methods. Regional cost estimates associated with these methods are presented in Tables 1 and 2.

Seedbed preparation methods involving mechanical farming implements include subsoiling, chiseling, moldboard plowing, offset disking, and tandem disking. Subsoiling and chiseling are deep tillage operations designed to break or shatter compacted soil layers that can inhibit germination, root development, and moisture infiltration (Brady 1980). Chiseling is less expensive than subsoiling due to shallower depths of implement operation and reduced power requirements. Regional cost estimates for subsoiling and chiseling are shown in Table 6. Wet, rocky soils, steeper slopes, and greater depths of subsoiling or chiseling necessary to break up compacted soil layers contribute to increased costs. For previously cited reasons of generally higher costs of goods and services, long distances to LRAM sites, and reduced equipment availability associated with small population bases, the Pacific Coast, Northeast, and Intermountain regions have greater chiseling and subsoiling costs than other regions (Table 6).

Table 6. Regional average costs and ranges for seedbed preparation practices.

Region	Estimate Type	Types of Seedbed Preparation				
		Subsoiling	Chiseling	Moldboard Plowing	Offset Disking	Tandem Disking
Pacific Coast	Average	30.06/acre	16.78/acre	15.27/acre	12.18/acre	9.08/acre
	Range	12-75/acre	8-25/acre	13-17/acre	8-15/acre	7-12/acre
Intermountain	Average	16.32/acre	10.65/acre	15.83/acre	14.52/acre	8.27/acre
	Range	9-24/acre	5-15/acre	10-21/acre	6-20/acre	5-9/acre
Northern Great Plains	Average	13.89/acre	9.92/acre	12.86/acre	10.54/acre	8.43/acre
	Range	6-25/acre	5-20/acre	3-20/acre	6-23/acre	4-23/acre
Southern Great Plains	Average	10.88/acre	6.69/acre	12.26/acre	7.16/acre	6.23/acre
	Range	4-19/acre	5-12/acre	4-18/acre	4-14/acre	3-12/acre
Central Lake	Average	11.84/acre	10.03/acre	11.99/acre	9.28/acre	7.77/acre
	Range	5-20/acre	4-18/acre	6-20/acre	4-13/acre	4-12/acre
Northeast	Average	15.36/acre	12.14/acre	15.57/acre	13.02/acre	10.41/acre
	Range	9-25/acre	9-20/acre	7-25/acre	7-19/acre	6-15/acre
Humid South	Average	13.74/acre	9.64/acre	11.44/acre	11.36/acre	8.13/acre
	Range	6-21/acre	5-20/acre	5-26/acre	6-20/acre	3-20/acre

Moldboard plowing, offset disking, and tandem disking are shallower tillage operations that can be used alone or in combination with subsoiling or chiseling, depending on site characteristics. All three practices are capable of reducing or eliminating existing vegetation and seed supplies of undesirable competing species while providing conditions conducive to seed germination and plant establishment (Vallentine 1989). Moldboard plowing has the greatest power requirements and is, therefore, more expensive than offset or tandem disking (Table 6). Moldboard plows are ineffective on hard, rocky, or clayey soils, making them far less versatile than offset or tandem disks, which are better adapted to unfavorable soil and vegetative conditions associated with noncultivated sites. Offset disking is generally more expensive than tandem disking (Table 6), but does a better job of killing and mulching existing vegetation with one pass of the implement (Vallentine 1989). As with subsoiling and chiseling, higher costs for plowing and disking were observed for Intermountain, Pacific Coast, and Northeast regions (Table 6). Well-developed farming enterprises in Southern Great Plains, Northern Great Plains, and Central Lake regions result in greater equipment availability and substantially lower mechanical seedbed preparation costs when compared to other regions (Table 6).

Soil Amendments

Normal plant growth depends on the nutrient-supplying capacity of soil to support and maintain critical physiological functions. Disturbed, degraded, and eroded soils are frequently lower in organic matter and other essential nutrients than their undisturbed counterparts (Aguilar, Kelly, and Heil 1988; Davidson and Ackerman 1993) and usually require the addition of supplemental fertilizer to encourage and sustain plant growth. Soil tests should be used to determine the kinds and amounts of nutrients that need to be added to the soil through fertilization.

Regional cost estimates for broadcasting and banding fertilizer are given in Table 7. Because each LRAM site will have different fertilizer requirements, the price of fertilizers is not included in these estimates. Local feed and seed dealers or U.S. Department of Agriculture, Natural Resources Conservation Services personnel can provide up-to-date fertilizer price information based on site-specific soil test recommendations.

Broadcasting fertilizer on the soil surface is the most widely used application technique. It is less expensive than banding, which involves placing narrow, continuous bands of fertilizer below the soil surface (Table 7). Although banding is a more expensive technique, it can reduce phosphorus fertilizer costs because it reduces fertilizer surface areas exposed to the soil, thereby proportionally reducing the amount

Table 7. Regional average costs and ranges for soil amendment application.

Region	Estimate Type	Types of Amendments			
		Fertilizer, Broadcasted	Fertilizer, Banded	Limestone and Gypsum	Non-traditional Materials*
Pacific Coast	Average	5.18/acre	6.26/acre	5.18/acre	50.00/hour
	Range	4.00-6.75/acre	5.25-7.03/acre	4.00-6.75/acre	30-70/hour
Intermountain	Average	4.59/acre	6.29/acre	4.59/acre	45.30/hour
	Range	3.00-7.50/acre	5.25-12.50/acre	3.00-7.50/acre	28-68/hour
Northern Great Plains	Average	3.14/acre	5.28/acre	3.17/acre	60.87/hour
	Range	2.00-5.25/acre	3.50-7.50/acre	2.50-5.25/acre	25-110/hour
Southern Great Plains	Average	3.18/acre	5.40/acre	3.85/acre	43.61/hour
	Range	2.00-5.75/acre	2.00-10.00/acre	1.00-8.00/acre	29-53/hour
Central Lake	Average	3.93/acre	6.22/acre	4.51/acre	35.64/hour
	Range	1.00-10.00/acre	2.00-12.00/acre	1.00-16.00/acre	12-56/hour
Northeast	Average	6.12/acre	8.67/acre	7.25/acre	42.32/hour
	Range	3.00-11.73/acre	7.00-13.00/acre	5.00-11.73/acre	28-68/hour
Humid South	Average	4.59/acre	6.83/acre	5.38/acre	31.45/hour
	Range	2.50-10.00/acre	5.00-15.00/acre	2.90-10.00/acre	22-45/hour
* These include municipal sludge, papermill wastes, compost, poultry litter, livestock manure, and food manufacturing wastes.					

that becomes essentially unavailable for plant uptake through fixation on soil colloids (Alexander 1977; Brady 1980). Broadcasting and banding costs, like those associated with seedbed preparation, were highest in Northeast, Intermountain, and Pacific Coast regions, lowest in Southern Great Plains, Northern Great Plains, and Central Lake regions, and varied depending on job size, application rates, slope steepness, and soil moisture content and rockiness (Table 7).

Extreme soil acidity or alkalinity have adverse effects on seed germination and plant growth. Correcting these problems is often accomplished by applying agricultural lime to acid soils and gypsum or sulfur to alkaline soils (Brady 1980). Soil tests should be used to determine the kinds and amounts of amendments needed to correct acidity and alkalinity problems.

Table 7 provides regional cost estimates for applying amendments necessary to adjust soil pH. Due to site-specific variability in the kinds and amounts of lime, gypsum, or sulfur needed to correct a given problem, prices associated with these amendments are not included in the cost estimates. Because these amendments are usually broadcast

on the soil surface, cost estimates closely mirror those associated with broadcasting fertilizer (Table 7). It should be noted, however, that in certain regions where soil acidity problems are common (i.e., Humid South and Northeast), costs for applying lime are higher than those for broadcasting fertilizer and reflect the increased demand for this practice.

Depending on region and proximity to various production, manufacturing, or processing facilities, additional sources of nontraditional soil amendments may be available that can complement or reduce the amounts of commercially produced fertilizer required to build soil fertility. These amendments include papermill wastes, municipal sludge, compost, poultry litter, livestock manures, and food processing wastes. These amendments can make a valuable contribution to most LRAM projects and their availability and use should be thoroughly explored. In addition to supplying soil nutrients, many of these soil amendments can also build soil organic matter, improve soil aggregate stability and resistance to erosion, and increase water holding capacity (Sharpley, Smith, and Bain 1993; Campbell, Folk, and Tripepi 1994; Feagley, Valdez, and Hudnall 1994; Pichtel, Dick, and Sutton 1994). Table 7 provides some very limited data concerning regional cost estimates associated with nontraditional soil amendments. As near as could be ascertained, these costs include the amendment and its loading, transportation, and subsequent spreading. Because of the extreme variability in nontraditional amendment type, source, availability, and desirability, these costs are only rough approximations and should not be used in any formal project cost estimating activity.

Revegetation

Rapid reestablishment of a vegetative ground cover to maintain site integrity and prevent further erosion is paramount in many LRAM projects. Reestablishing vegetation can be accomplished through direct seeding, hydroseeding, or transplanting of species adapted to general climatic and edaphic conditions of the site. Direct seeding techniques include drill seeding, hydroseeding, and broadcasting seed onto soil surfaces using ground equipment or aircraft. If possible, drill seeding should always take place in prepared seedbeds and broadcasting seed should only be considered in situations where there is some assurance that sown seeds can be covered with soil to increase the probability of successful revegetation (Vallentine 1989).

Drill seeding uniformly distributes and covers seed at the proper planting depth in a single farming operation, resulting in enhanced germination, establishment, and stand uniformity when compared to broadcasting and hydroseeding. Broadcasting and hydroseeding may, however, be the only means of seeding on remote or inaccessible

sites where rough terrain, steep slopes, and wet or rocky soils make seedbed preparation and drill seeding impractical. Table 8 provides regional cost estimates for drill seeding, hydroseeding, and broadcasting seed with ground equipment and aircraft. Due to regional differences in species adaptability and availability, the price of seed is not included in cost estimates for drill seeding and broadcasting. Cost estimates for hydroseeding, on the other hand, include the price of regionally adapted seed, starter fertilizer, and mulch.

Drill seeding costs were highest in Pacific Coast and Intermountain regions where the more unfavorable site conditions associated with rangeland revegetation projects result in increased prices (Table 8). Conversely, drill seeding costs were lowest in Northern Great Plains, Southern Great Plains, and Central Lake regions where favorable site conditions associated with production agriculture result in lower prices. The cost of broadcasting seed with ground equipment and aircraft is lower than that for drill seeding in all regions (Table 8). Compensating for uneven seed distribution and poorer germination responses associated with either form of broadcasting, however, requires increased seeding rates, which may offset any perceived savings attributed to these methods. Compared to drill seeding and broadcasting, hydroseeding is extremely expensive and should be restricted to LRAM sites for which no other alternatives exist (Table 8).

Table 8. Regional average costs and ranges for revegetation using direct seeding methods.

Region	Estimate Type	Types of Direct Seeding Methods			
		Drill Seeding	Broadcast Seeding	Aerial Seeding	Hydroseeding
Pacific Coast	Average	16.62/acre	6.00/acre	9.55/acre	2032.00/acre
	Range	8-30/acre	5-8/acre	6-14/acre	1129-4791/acre
Intermountain	Average	13.39/acre	5.49/acre	6.95/acre	2054.00/acre
	Range	5-47/acre	3-7/acre	5-15/acre	1200-4791/acre
Northern Great Plains	Average	7.28/acre	6.20/acre	6.23/acre	1717.00/acre
	Range	3-14/acre	5-7/acre	3-12/acre	968-4600/acre
Southern Great Plains	Average	7.83/acre	5.12/acre	4.97/acre	1716.00/acre
	Range	5-19/acre	3-7/acre	4-6/acre	1200-2300/acre
Central Lake	Average	9.19/acre	4.68/acre	6.02/acre	2750.00/acre
	Range	2-16/acre	2-11/acre	5-7/acre	500-5000/acre
Northeast	Average	11.32/acre	6.98/acre	10.30/acre	2568.00/acre
	Range	6-18/acre	5-13/acre	6-14/acre	1500-3500/acre
Humid South	Average	10.38/acre	6.01/acre	6.43/acre	1533.00/acre
	Range	4-20/acre	4-12/acre	5-10/acre	1000-2000/acre

Under special circumstances or within some vegetation types, it may be desirable to transplant vegetation rather than establish it from seed. This is especially true for many shrubs and trees that, because of their highly specific germination requirements and/or slow growth characteristics, probably would not or could not establish from seed on many LRAM sites.

Cost estimates for transplanting bare root and containerized tree and shrub saplings/seedlings vary significantly within and between regions (Table 9) depending on species, growth and maintenance requirements, age, and size. These cost estimates are based on bulk purchases of at least 1000 trees or shrubs; prices will increase if smaller lots are purchased. It should be noted that for many species, costs can significantly exceed those presented in Table 9 and reliable estimates should be based on site-specific recommendations and requirements. Desirable, intensively managed, greenhouse grown species with exacting germination and growth requirements will be more expensive to purchase and transplant than fast-growing species raised in outdoor

Table 9. Regional average costs and ranges for revegetation using transplants.

Region	Estimate Type	Types of Plant Materials Available for Transplanting			
		Trees and Shrubs, Bare Root*	Trees and Shrubs, Containerized*	Grass Sods**	Grass Stolons and Rhizomes
Pacific Coast	Average	0.48/plant	1.35/plant	3.15/sy	***
	Range	0.22-0.60/plant	0.80-2.50/plant	2.00-4.60/sy	***
Intermountain	Average	1.59/plant	10.29/plant	2.80/sy	***
	Range	0.75-4.79/plant	1.26-30.00/plant	1.90-4.10/sy	***
Northern Great Plains	Average	0.71/plant	1.57/plant	1.85/sy	***
	Range	0.24-1.10/plant	0.55-5.14/plant	1.00-2.47/sy	***
Southern Great Plains	Average	0.90/plant	2.55/plant	3.25/sy	59.01/acre
	Range	0.36-2.00/plant	1.00-4.00/plant	1.00-5.00/sy	38.00-95.00/acre
Central Lake	Average	0.39/plant	1.38/plant	2.32/sy	***
	Range	0.23-1.07/plant	0.60-4.25/plant	2.00-2.50/sy	***
Northeast	Average	0.26/plant	0.65/plant	1.10/sy	***
	Range	0.12-0.46/plant	0.30-1.05/plant	0.40-1.65/sy	***
Humid South	Average	0.31/plant	0.80/plant	2.58/sy	72.73/acre
	Range	0.11-1.09/plant	0.40-2.00/plant	2.20-3.50/sy	32.35-130.00/acre
* These costs are based on purchases of at least 1000 units. ** sy = square yard *** Indicates data not available or not applicable					

flats. Containerized plants, regardless of species, age, or size, will be more expensive than bare root counterparts (Table 9) due to increased survivability following transplantation (Utah Agricultural Experiment Station 1979; Blauer, et al. 1993) and the ease with which they can be transported, handled, and mechanically planted. Transplanting the very limited selection of trees and shrubs adapted to the arid/semiarid Intermountain region (Blauer, et al. 1993) is nearly twice as expensive as other regions (Table 9) because water is usually applied to individual plants following transplanting to increase chances for long-term survival (Pendleton, Frischknecht, and McArthur 1992). Under exceptionally arid conditions, irrigating plants for several weeks after transplanting may be essential for plant survival (Utah Agricultural Experiment Station 1979). Conversely, the greater selection of trees and shrubs adapted to Northeast, Humid South, and Central Lake regions, where water application following transplanting is usually not required for survival, results in much lower costs.

Transplanting grass stolons, rhizomes, or sod is occasionally used in place of seeding to establish vegetation on disturbed sites. Bermudagrass [*Cynodon dactylon* (L.) Pers.] is the most common grass established by this method (Burton and Hanna 1985) and is used primarily in the Southern Great Plains and Humid South regions (Table 9). Other rhizomatous and stoloniferous grasses can be of local importance but cost estimates for transplanting them are not readily available. Grass sod is frequently used in small urban landscaping projects where anticipated benefits outweigh transplanting costs. On larger LRAM projects that will be less intensively managed, grass sod transplanting costs are probably prohibitive except under very specific circumstances. These grass transplanting options are all significantly more expensive than seeding (Tables 8 and 9) and should be restricted to sites where no other viable alternatives exist.

Safeguards for Revegetation Success

Immediately following a revegetation effort, surface mulching is often needed to protect the site from further erosion until recently seeded or transplanted vegetation becomes established. Surface mulches can impede runoff and erosion, increase available soil water, lower soil temperatures, reduce evaporation, and conserve moisture available to plant roots (Hungerford and Babbitt 1987). Straw or hay, applied at a rate of 2 tons/acre, is the most common surface mulching practice. To ensure that straw mulches remain on recently revegetated areas, application is usually followed by disking or crimping the mulch into the soil surface with various farm implements to prevent mass movement (Utah Agricultural Experiment Station 1979). Under extreme conditions, fabrics and netting stapled over straw mulches are used to

hold it in place. Regional cost estimates for straw mulching (2 tons/acre) held in place by disking, crimping, and fabrics/netting are shown in Table 10. The cost of fabrics and netting are presented separately and should be added to the costs associated with disking straw mulch into the soil surface (Table 10). Costs vary depending on straw availability and slope steepness, which affects equipment selection and application method (blower versus hand application).

Various chemical tackifiers are also used in place of disking, crimping, fabrics, and netting to hold straw mulches in place. Cost data concerning tackifiers was very limited but suggested that costs would be about 40 percent greater than those associated with straw mulching followed by disking (data not shown).

Chemical mulches, such as asphalt emulsions, can also be used in place of straw. They can hasten germination and development of some grasses, maintain moisture in the topsoil for longer periods of time, and increase soil temperatures during colder portions of the growing season; however, hail and high intensity rains tend to weaken or

Table 10. Regional average costs and ranges for materials to safeguard revegetation success.

Region	Estimate Type	Types of Safeguarding Materials			
		Straw Mulch , Crimped*	Straw Mulch, Disked*	Gravel Mulch**	Fabrics and Netting***
Pacific Coast	Average	461.33/acre	461.33/acre	20.64/cy	1.49/sy
	Range	330-616/acre	330-616/acre	18-22/cy	0.60-3.40/sy
Intermountain	Average	383.63/acre	416.36/acre	17.23/cy	1.56/sy
	Range	270-500/acre	270-520/acre	16-19/cy	0.74-3.00/sy
Northern Great Plains	Average	304.72/acre	323.61/acre	16.93/cy	2.16/sy
	Range	160-500/acre	160-530/acre	10-19/cy	0.45-5.85/sy
Southern Great Plains	Average	385.00/acre	385.00/acre	14.53/cy	1.61/sy
	Range	230-490/acre	230-490/acre	13-16/cy	0.54-6.35/sy
Central Lake	Average	458.00/acre	466.00/acre	22.42/cy	1.58/sy
	Range	220-700/acre	220-750/acre	16-41/cy	1.50-1.71/sy
Northeast	Average	476.00/acre	476.00/acre	22.72/cy	1.71/sy
	Range	220-1050/acre	220-1050/acre	9-35/cy	0.72-4.68/sy
Humid South	Average	335.00/acre	335.00/acre	26.86/cy	1.86/sy
	Range	250-500/acre	250-500/acre	18-35/cy	1.10-7.02/sy
* These cost estimates are based on straw application rates of 2 tons/acre ** cy = cubic yard *** sy = square yard					

destroy their integrity and usefulness (Bement, et al. 1961). Extremely limited cost data from the Pacific Coast, Intermountain, and Central Lake regions indicates that asphalt emulsions are similar in price to straw mulch followed by disking (data not shown).

Gravel can also be used as a mulching material, although it is more frequently used as a deep, permanent mulch that prevents plant growth or as an erosion control material. Thin layers of gravel are effective for controlling wind erosion on highly susceptible revegetated sites due to increased soil surface coverage and roughness (Fryrear and Bilbro 1994). Provided the gravel layer is not thick and continuous, plant germination and establishment should not be compromised. Table 10 provides regional cost estimates for gravel. Remoteness of the job site, proximity to quarries, and gravel size contribute to price variability. Generally, gravel is too expensive for use on large revegetated areas requiring mulching for enhanced plant establishment, water conservation, and wind erosion control. Other alternatives should be investigated.

4 Summary

This report provides current, regionally-based cost estimates for component activities associated with rehabilitation and maintenance of Army training lands. Data used to prepare these estimates were obtained from numerous Federal, State, and private agencies involved in similar types of activities. Although there were numerous exceptions, land rehabilitation and maintenance costs are generally higher within Pacific Coast, Northeast, and Intermountain regions. This is a reflection of the higher costs of goods and services in Pacific Coast and Northeast regions, and greater distances to job sites coupled with reduced equipment availability and generally poorer soil conditions in the Intermountain region. Lowest land rehabilitation and maintenance costs were generally observed within Northern Great Plains, Southern Great Plains, and Central Lake regions. Well-developed agricultural production enterprises within these regions results in greater equipment availability, higher proportions of experienced, agriculturally oriented contractors and vendors, and reduced costs.

Land rehabilitation and maintenance costs can and do vary significantly within and between regions due to differences in climate, geology, soils, vegetation types, remoteness of job sites, project size, skilled labor sources, contract types, and equipment availability and ownership. Therefore, data in this report should be used with caution and only as a general reference for decisionmaking. Actual cost estimates presented in this report will change with time and may require periodic update to remain current. Relative costs, the ratio of prices between similar types of activities (i.e., drill seeding versus broadcast seeding), should, however, remain relatively constant over time, ensuring their future applicability.

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Appendix B: Approximate Retail Prices of Common Herbicides

Herbicide	Unit	Unit Cost	Herbicide	Unit	Unit Cost	Herbicide	Unit	Unit Cost
2,4-D amine	Gallon	13.75	Cobra	Gallon	117.51	Marksman	Gallon	25.51
Aatrex 4L	Gallon	12.62	Crossbow	Gallon	43.00	Poast Plus	Gallon	48.39
Aatrex 80W	Pound	3.00	Diquat	Gallon	77.80	Princep 4L	Gallon	16.80
Accent	Pound	427.20	Dowpon M	Pound	2.15	Prowl	Gallon	29.76
Ally	Pound	455.36	Dual 8E	Gallon	63.61	Pursuit	Gallon	594.87
Amitrol-T	Gallon	21.50	Eptam 7E	Gallon	26.29	Ramrod	Gallon	14.93
Aquazine	Gallon	8.85	Eptam 10G	Pound	0.39	Roundup	Gallon	46.15
Assure II	Gallon	139.00	Eradicane	Gallon	23.58	Select	Gallon	204.24
Arsenal	Gallon	184.54	Frontier	Gallon	118.00	Sencor	Pound	24.16
Banvel	Gallon	74.45	Fusilade	Gallon	86.00	Spike 5G	Pound	3.00
Basagram	Gallon	64.47	Goal 1.6E	Gallon	77.00	Spike 80W	Pound	21.50
Beacon	Pound	400.96	Gramoxone	Gallon	30.76	Spike 20P	Pound	8.60
Bicep	Gallon	35.83	Harmony	Pound	191.52	Stinger	Gallon	466.22
Bladex 4L	Gallon	23.93	Hyvar XL	Gallon	51.00	Sutan +	Gallon	20.67
Bladex 90DF	Pound	5.31	Lasso	Gallon	27.98	Tordon 22K	Gallon	91.24
Bronco	Gallon	26.86	Lariat	Gallon	19.22	Tough	Gallon	86.80
Buctril	Gallon	52.45	Lexone 4L	Gallon	142.70	Treflan	Gallon	33.18
Clarity	Gallon	85.10	Lorox Plus	Pound	16.01	Velpar	Pound	29.50

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